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generation. The horses which were thus cut out of the first selection by the third selection, occurring some thirty or more years later, were more largely sons of young sires than sons of old sires, with the net result that those left were sons of sires averaging 13.5 years of age.

This is the process which has been going on from generation to generation—each selection reducing the number of horses in earlier generations which are left to breed on to later generations. Chester proved some years ago that all known standard trotters were descended in the male line from one or another of no more than seventeen foundation horses. While these all stand as having been progenitors of trotters, the majority of them represent what are now extinct families, so that the trotters as now bred come in the male line from only six or eight horses.

The process set forth explains how it comes about that, in examining the pedigrees of any trotting stock, the further we go back in those pedigrees the older the sires appear, but it does not explain *why* a late selection cuts off young sires and preserves old sires of earlier generations.

That is the supreme question I am asking biologists. I have asked it in several forms before without getting a reply commensurate with what I consider the importance of the question. It is hoped that the present form, accompanied by the explanation upon which the form is based, will bring forth a genuine effort to explain *the cause* of these remarkable facts.

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THE LOGIC OF CHANCE IN PROBLEMS OF GENETICS

THE literature at present appearing dealing with problems of genetics and evolution teems with uncertainty and inexactness in the use and misuse of the word "chance." Some definite understanding of the significance of the concept as a legitimate category of scientific reasoning seems desirable. At any mention of the word chance, some listener is sure to rise in protest with the old adage—"There is no chance, it's only your ignorance." The acceptance or the rejection of this bit of prophecy depends on the ultimate postulate of the absolute uniformity of nature. The truth of this postulate is a metaphysical question with which the ordinary student of genetics is not concerned. He is reminded of the fact that Darwin and all after him have used the word "chance" in many ways and he demands a definition of the term which shall meet his usage without involving metaphysical postulates.

The particular problem of genetics arises within a more or less precise universe of discourse. Within it lie a broad range of biological phenomena which the student of the problem is bound to take into consideration. Without this definite universe of discourse lie a still greater range of phenomena—chemical, physical, geological, etc.—which he is bound to neglect. His problem can not be made to encompass the whole universe, simply because the multiplicity of facts regarding the universe impede rather than advance the progress of the understanding of his particular problem. His universe of discourse must be precise and relatively small to be serviceable. Within this limitable universe of discourse the observer will discover certain regularities. These will constitute for him the laws. Certain other groups of phenomena will appear seemingly without regularities. These are chances. The reduction of chance to law will consist, ordinarily, of determining more facts regarding the chances and also in so extending the boundaries of the original universe of discourse that new and theretofore unobservable regularities will appear.

In problems of genetics the occurrence of an event said to be due to chance may be ascribed to two separate but independent sets of conditions. The internal conditions are those which are entirely confined to the original universe of discourse of the problem—as for instance, the conditions of the gametes in the chance union of a Mendelian hybrid. The external conditions are those which are not centered in the immediate elements. They are such as age, strength, and the like, of the gamete producing animals. Let ϕ represent the chance occurrence of any event, and let $a, b, c, \ldots$ represent a series of internal conditions either known or unknown, and let the coefficients $A, B, C, \ldots$, etc., represent the intensive value of a, b, c in determining the result. Similarly let m, n, o represent certain external conditions and M, N, O their coefficient of intensive value. Then the formula for the chance occurrence, ϕ, of an event becomes

$$\phi = f\ (Aa, Bb, Cc\ \ldots\ Mm, Nn, Oo\ \ldots)$$

As far as I can find in the recent literature of genetics the concept of chance has appeared with three different uses. It is used first to describe the degree of probability for the crossing of individuals which differ more or less from one another. In this sense one may say the chance of producing a cross varies with the relative distance of the individuals producing the gametes in the Linnean classification. The second use of chance is that concerned with the occurrence of a mutant in those theories of the origin of variation through mutation. In this sense one speaks of a mutant as a chance or sport variety. The third type of usage has grown up in the literature of Mendelian crossing and of sex determination according to the male and female producing spermatozoa of arthropods. In this third type of instances the chance is reduced to the occurrence of one of two events.

It is the purpose of the present note to apply the formula of chance as previously given to these three separate uses of the term.

1. Take, for example, the type of the first usage mentioned above—the chance of a cross between different varieties and different Linnean species. If ϕ represents the chance of a cross between any two individuals, then the occurrence of that cross is determined by a series of internal conditions a, b, c, etc., which rest entirely within the structure of the gamete, as for instance, the innate characters of the centrosomes or the chromosomes. These are entirely contained within the cell itself and are, therefore, independent of any external modification. It is they, in all probability, that determine the amount of cleavage of a zygot produced from the union of gametes from individuals of different species, as for instance, when the eggs of *Rana fusca* are fertilized by sperm of the *Triton,* but development stops suddenly after a few irregular cleavages. The logician would say that these internal factors represented the conditions contained within the original universe of discourse of the particular problem in question. The union is also determined by external conditions m, n, o, etc., which lie without the gametes, as for instance, the ripeness of the eggs, as shown by Hertwig in experiments on the sea-urchin, or by the presence of alkaline in the water, as given by Godlewski when he crossed the sea-urchin with a crinoid *Antedon.* These external conditions are those that lie without the original universe of discourse of the problem.

2. Take, as a second usage of chance, the chance production of

a mutant. Let ϕ represent again such a chance occurrence. Then ϕ is a function of a, b, c, certain difficultly understood conditions which seem to reside within particular gametes and produce a new variety, differing considerably from the parental forms. The various occurrence of mutants among domestic animals probably resulted from such internal conditions. The very light silver cat, Chinnie, made his appearance about 1878, and has been the stock ancestor from which all the line-bred silver cats have since been produced. No external factors determining the occurrence of this sport could be traced. DeVries, who, of course, emphasizes these chance occurrences of the mutants, seems to believe that the internal conditions are alone responsible for these chance variations, yet MacDougal is said to have produced mutants of the evening primrose by salt solutions. If this observation is borne out by subsequent investigation, such mutant-producing factors would be represented by m, n, o of our formula, the external conditions for the production of chance occurrence ϕ, in this case the mutant.

3. Lastly, the concept of chance is of frequent occurrence in Mendelian literature. The Mendelian formula for the production of generation F^{II} demands that the independent inheritable characters shall separate in the gametes of F^{I} and recombine according to the pure law of chance, and Mendel's work on peas bears this out to a remarkable degree of accuracy. Similarly if we believe that the sex of certain arthropods is determined by male and female producing spermatozoa, but the egg is neutral, we must assume that the determination of sex is purely a matter of the chance union of the male or the female producing spermatozoa with a neutral egg. Nor in this case is the formula of ϕ without its significance. The work on certain parthenogenetic forms shows that certain spermatozoa, those without the accessory chromosome, are degenerate and presumably non-functional. This degeneration is obviously an internal condition, a, of the formula, but since it is known that various sex ratios exist all the way from the approximate one to one of many of the mammals to the very disproportionate ratios, approaching parthenogenesis in the nematodes, it may be supposed that this internal degeneration of certain of the spermatozoa is itself the function of other and unknown variables. Again, the external conditions m, n, o, such as age, maturity, nutrition, etc., may also have an influence upon the chance occurrence of the sex-producing factor of the spermatozoa.

The formula has perhaps an advantage, therefore, in suggesting a definite usage of the concept of chance in these problems, and also of suggesting, what writers sometimes confuse, the marked difference between external and internal determining factors. It rests upon a definite logical issue. Every scientific problem arises in a more or less definite universe of discourse. The limits of this universe of discourse determine the possibility of discovering regularity among the experiences it defines. Such internal regularity gives law, its absence, chance. This definition, therefore, gives to chance a definite and precise meaning, capable of an exact usage in scientific enquiries. It does not involve the affirmation nor the denial of the ultimate uniformity of nature.

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